3S^2: Behavioral Response Studies of Cetaceans to Navy Sonar Signals in Norwegian Waters

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LONG-TERM GOALS

Data on the responsiveness of cetaceans to sonar signals are lacking, with only a few species having been studied in relation to a few types of sonar signals, mostly SURTASS-LFA (Nowacek et al., 2007). Marine mammals have been shown to react to underwater noise (Richardson et al., 1995), and captive research has documented hearing (Schlundt et al., 2000) and stress (Romano et al., 2004) effects at high received levels. To reduce the risk of behavioral or physiological effects, a number of mitigation protocols have been developed, such as shut-down procedures when animals are sighted nearby. Another mitigation protocol is the 'ramp-up' protocol in which source levels are gradually increased prior to the onset of full-level transmissions. This protocol is thought to give nearby animals some time to move away before sonar transmissions reach maximum levels. However, it is unknown whether or not this protocol is actually effective.

In this research program, we will conduct primary research on these two knowledge gaps. First, we will address how two poorly-studied target species of wild cetaceans, that have been reported to strand during sonar exercises, respond to experimental presentations of sonar. Secondly, we will modify our existing 3S experimental design to assess experimentally whether 'ramp-up' is an effective protocol to reduce risk of harm.

Sonar-related strandings have commonly involved Ziphiids in temperate or tropical waters, but have also included species that are more common the North Atlantic: the Northern bottlenose whale (Canary Islands), and minke whale (Bahamas). It is unclear whether the low numbers of Northern bottlenose whale and minke whales documented in sonar-related stranding events result from lower sensitivity to sonar or because they are present in lower numbers in the areas where documented stranding events have occurred. To resolve this question, directed research on the behavioral responses of these two species is needed (Tyack et al., 2004). The current 3S research effort (see related programs) with killer, sperm, and long-finned pilot whales provides a dataset that enables comparative analysis of behavioral response sensitivities because the field experiments will follow the same protocol. Broader comparative data are also available from other research teams.

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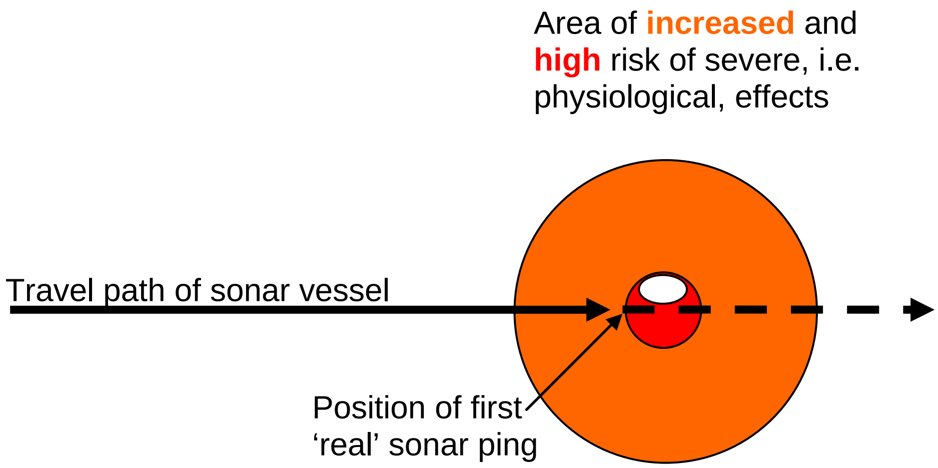

Figure 1. ***Animals placed near the position of the first full-power sonar transmissions are at a higher risk of severe effects such as physiological effects.***

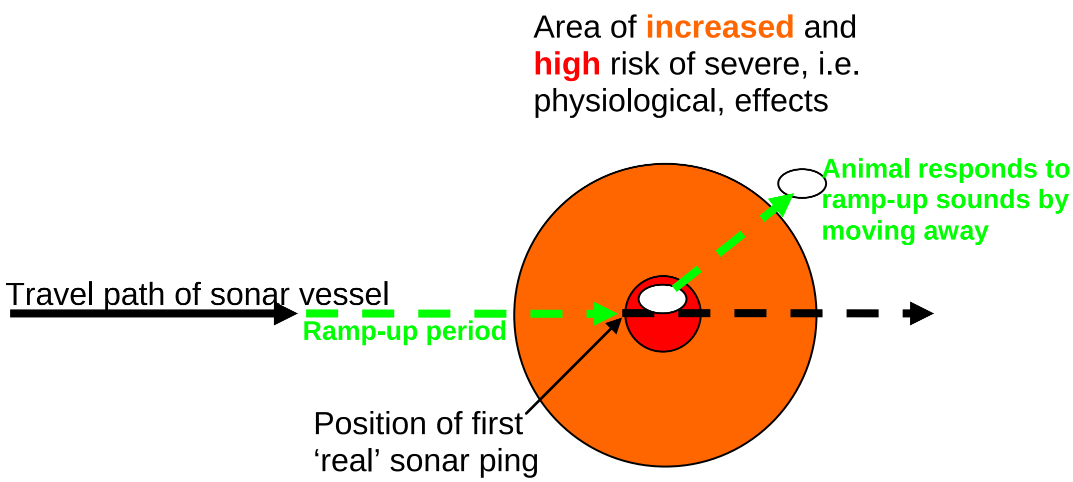

Figure 2. ***Sonar sounds are started earlier at lower levels and are gradually increased to full power at the planned position. These additional 'ramp-up' transmissions increase the total amount of sound energy transmitted into the ocean, but are thought to reduce risk by giving animals in the zone of increased risk time to move away.***

Interestingly, very similar field data are needed to address the question of whether or not 'ramp-up' is an effective mitigation protocol. Animals located close to the location of the first full-level sonar transmission are at the greatest risk of severe effects such as strong behavioral responses or hearing effects such as temporary or permanent threshold shift (Fig. 1). The 'ramp-up' protocol could be effective if it gives animals time to move away from the immediate location of the full-level sonar

pings (Fig. 2). Thus, the ‘ramp-up’ protocol is itself is based upon the principle of behavioral response – in this case a response that protects the animals from receiving intense sound levels.

More specifically, it is assumed that animals will avoid the sounds during ‘ramp-up’, even if the sounds are transmitted at relatively low source levels. Avoidance has been observed in several studies of marine mammals in the presence of noise (Richardson et al., 1995), but does not necessarily always occur (Miller et al., 2009). It is even possible that starting the sonar sounds at low levels will cause the animals to acclimate to the sound, thereby reducing any tendency to avoid the source. Second, it is assumed that animals will be able to sense the direction and path of the oncoming sound source and formulate a good direction to move away from the sound source. For an oncoming vessel, moving directly away from the sound source would leave the animal within the vessel path and would not be an effective way to reduce exposure. Moreover, it may take some time for animals to determine the direction and speed of movement of the vessel to make appropriate avoidance movements.

To study whether or not ‘ramp-up’ is an effective mitigation tool, we propose to quantify the likelihood of behavioral change, specifically avoidance, as a consequence of exposure to the ‘ramp-up’ signals. Thus, it becomes critical to understand what factors affect the probability of avoidance (e.g. received level at the animal, distance of the source, frequency or amplitude of the sonar, sound propagation conditions, behavioral state of the animal). As in behavioral response generally, we seek to understand what the consequences for the animals are, but in the case of ‘ramp-up’ we specifically would like to know whether any avoidance behavioral change leads to effective protection from high sound exposure levels.

OBJECTIVES

In research to date under related ONR grant N000140810984, the 3S collaborative team has recorded the behavior of 4 killer, 6 longfinned pilot, and 4 sperm whales before, during, and after experimental sonar presentations at 2 different frequencies (1-2 kHz and 6-7 kHz) along with no-sonar control approaches and playback of natural killer whales sounds (see Kvadsheim *et al.*, 2007, 2009).

In this new project, our objectives are to: 1.) Expand our unique comparative experimental dataset to include potentially more sensitive and difficult to study, Northern bottlenose whale (*Hyperoodon ampullatus*, family Ziphiidae) and minke whale (*Balaenoptera acutorostrata*, family Balaenopteridae); 2.) Conduct a directed study of the effectiveness of ramp-up as a mitigation method with abundant and relatively easy-to-study humpback whales, *Megaptera novaeangliae*; 3.) Record sufficient no-sonar baseline data of all target species to adequately describe the behavioral significance of recorded changes in behavior and to statistically compare experimental records with baseline records; and 4.) Develop collaborations between the 3S research group with other research groups undertaking similar projects to pool data where appropriate, share expertise and reduce overall project costs.

APPROACH

We plan to conduct at least two full CEE trials in years 2-4 (2011-2013), with the specific timing of the CEE trials to be based upon our preparation success in year one. During CEE trials, we will seek to quantify responses of *Hyperoodon* and minke whales to sonar signals at 1-2 kHz and 6-7 kHz following the same protocol we have used with killer, pilot and sperm whales (see related research). During the same trials, when we encounter abundant humpback whales, we will conduct tests of the effectiveness of ‘ramp-up’ (see below).

We will undertake 2 low-cost baseline trials at or near the end of the sonar-exposure experimental data collection so that collection of specific baseline data-sets can be collected. The first of the 2 trials will collect baseline data on longfinned pilot, offshore killer and sperm whales in the Lofoten 3S study area. A second 3-4 week baseline cruise is planned for the northerly study species in 2012.

The research is carried out by an international collaborative team from the Sea Mammal Research Unit (SMRU), Woods Hole Oceanographic Institution (WHOI), Norwegian Defense Research Establishment (FFI), and Netherlands Organization for Applied Scientific Research (TNO). SMRU is home to PI Patrick Miller. WHOI is providing scientific advice from Dr. Peter Tyack as well as the provision of v2 Dtags. Project management and logistic support, including acquisition of research vessels and permitting are managed through FFI, led by Dr. Petter Kvadsheim. FFI also provides biological and tagging expertise, including the development of a new pneumatic launching system for the Dtag, headed by Lars Kleivane. TNO contributes an advanced towed array system for recording and detecting marine mammal sounds (Delphinus), a multi-purpose towed source (Socrates), and staffing during the cruises under the leadership of Frans-Peter Lam, with collaboration from René Dekeling of the Royal Netherlands Navy. The Socrates source is capable of transmitting 1-2 kHz signals at a source level of 214dB re1µPa m, and 6-7 kHz signals at a source level of 199dB re1µPa m.

WORK COMPLETED

As of the end of September, 2010, we have conducted 3 trials in the summer of 2010. The first was a trial dedicated to obtain baseline behaviour of the 3S species. The second and third trials were conducted to give us additional experience with acoustic and tagging methodologies for the difficult $3S^2$ species, the minke whale and the Northern bottlenose whale. As detailed below in ‘results’ all three trials achieved their primary objectives with only minor gaps in goal accomplishment. Based on our experience in 2010, the 3S collaboration has determined that we have sufficient experience to schedule a full CEE trial with the 3S2 species in June, 2011. We have also collected sufficient baseline data to aid in analysis and interpretation of the 3S sonar exposures to longfinned pilot and sperm whales, but a gap remains in baseline data collection for killer whales which were not sighted at all in the 2010 effort.

RESULTS

$3S^2$ preparation trials in Iceland and Canada:
In the Iceland trial, our objective was to gain tagging experience with the new species in Skalfjandi Bay. Although humpback, minke, and Northern bottlenose whales are regularly sighted in the study sight, only minke whales were sighted in the 2010 effort. We spent roughly 80 hrs working with minke whales, with very little success. One Dtag was attached, but the tag slipped off after just 5 minutes. Two other whales were approached closely enough for tagging attempts, but both were missed. Our conclusion is that minke whales are an extremely difficult species to tag with existing systems, and that even when a tag is attached they have a tendency to slide off prematurely. This represents a substantial challenge to our ability to conduct experiments with minke whales.

In the Canada field trial, our objectives were to test passive acoustic detection and tracking technologies with Northern bottlenose whales. The research was conducted in collaboration with Hal Whitehead of Dalhousie University using his research sailing vessel. An additional goal was to collect blow samples from the whales, partly to asssess how approachable Northern bottlenose whales might

be for tagging. Both objectives were well met, with Northern bottlenose whales being regularly sighted in the Gully. Acoustic detection methods were highly effective with animals more often being detected acoustically before being seen. Existing DCL software Pamguard© was highly effective at detecting Northern bottlenose whale clicks and calculating bearing angles. We found the whales to be very approachable, with the whales themselves often moving toward the research sailing vessel. Two blow samples were successfully collected.   Our conclusions from that trial are that acoustic methods for tracking and tagging Northern bottlenose should be effective and helpful, and that the species should be reasonably approachable for tagging and certainly more approachable than most beaked whales species. An important caveat is that no tags were actually attached in the Canada trial so there remains some risk for the 2011 $3S^2$ CEE trial that Northern bottlenose whales will prove more difficult to tag than is curently foreseen.

3S-2010 baseline cruise:
The overall objective of the trial was to collect baseline behaviour of the 3S target species using the same observation systems as were used in the 3S sonar experiments. The primary tasks of this trial were to: 1.) Dtag killer whales, pilot whales and sperm whales with DTAG recording behavior, and systematically record observational and towed array data following the 3S protocol (includes pre-tagging observation protocol); 2.) carry out control experiments in which Dtagged animals are exposed to a playback of killer whale sounds; 3.) Tag killer whales, pilot whales and sperm whales with a DSL-2000 Camera tag to record indications of prey-interactions; and 4.) Coordinate support of Dtags with the Bolga team.

This cruise was highly successful in achieving its primary tasks, despite some equipment problems, with the exception that <u>no</u> killer whales were sighted despite intensive searching. A total of 61 hrs of baseline observations matching the 3S experiments was obtained. We attached Dtags to 3 sperm whales, with good baseline follows and CTD accomplished. KW sound playbacks and secondary tagging was conducted for 2/3 sperm whales. A total of 11 Dtags were attached to long-finned pilot whales (2 by ARTS system), with 5 usable baseline follows and CTD. Good visual tracking and towed array acoustics recordings were made throughout the trial, as were observations of group-level behaviour with pilot whales, including observations before, during, and after tagging attempts.

Table I. Baseline follows on 3S species during 3S-2010 baseline trial

Species	Start date and time	End date and time	duration	sight #	tag code	comments
Long-finned pilot	23/05/2010 12:49:27	23/05/2010 21:35:26	08:45:59	16	gm10_143a	
Long-finned pilot	24/05/2010 02:28:37	24/05/2010 04:02:53	01:34:16	17	LpW_10pm1N	non-Dtag track
Long-finned pilot	01/06/2010 20:39:20	01/06/2010 22:16:59	01:37:39	233	gm10_152b	
Long-finned pilot	06/06/2010 04:17:13	06/06/2010 14:47:59	10:30:46	238, 240	gm10_157a,b	tag b was primary
Long-finned pilot	07/06/2010 17:03:43	07/06/2010 19:59:46	02:56:03	251	gm10_158d	
sperm whale	27/05/2010 11:59:01	28/05/2010 04:20:00	16:20:59	29	sw10_147a	Stronstad broke down
sperm whale	29/05/2010 05:00:22	29/05/2010 15:02:53	10:02:31	102	sw10_149a	
sperm whale	30/05/2010 13:45:00	30/05/2010 22:35:59	08:50:59	166	sw10_150a	bad weather

We conducted 2 playbacks of killer whale sounds and 3 control sound playbacks to pilot whales, with clearly observable reactions to the killer whale playbacks. A total of 4 supporting tags were deployed on pilot whales. For $3S^2$ species, only minke whales were seen, but no tagging attempts were made. 165 hrs of cutting-edge archived tag data, Dtags and other tags that record video and speed data, combined with systematic visual and acoustic observations yield in a useful data-set to describe the natural behaviour of sperm and long-finned pilot whales. Coordination with Bolga team was highly effective with mutual equipment, sightings and tagging support. Those data will support analyses of the 3S experiments conducted on the same species in the same locations in 2008 and 2009.

Of particular interest is our success in accomplishing additional playbacks of killer whale sounds to subject animals. The goal of those playbacks is to compare how the subjects respond to natural sounds in their environment with how they might respond to sonar. Adding our 2010 efforts to the existing database, we now have conducted 14 killer whale playbacks, 4 to killer whales themselves and 5 each to long finned and sperm whales. Our initial results indicate that killer whales respond in a negligible fashion to playback of their conspecific sounds. In striking contrast, very clear and strong reactions to playback have been observed in both sperm and longfinned pilot whales. The reaction of longfinned pilot whales has been particularly striking: in 4 of 5 playbacks longfinned pilot whales turned to approach the speaker (Fig 3). In contrast, the reaction of sperm whales tends to be avoidance. For both species, the level of reaction to playback of killer whales sounds appears to be at least as strong as changes in behaviour observed during sonar exposures.

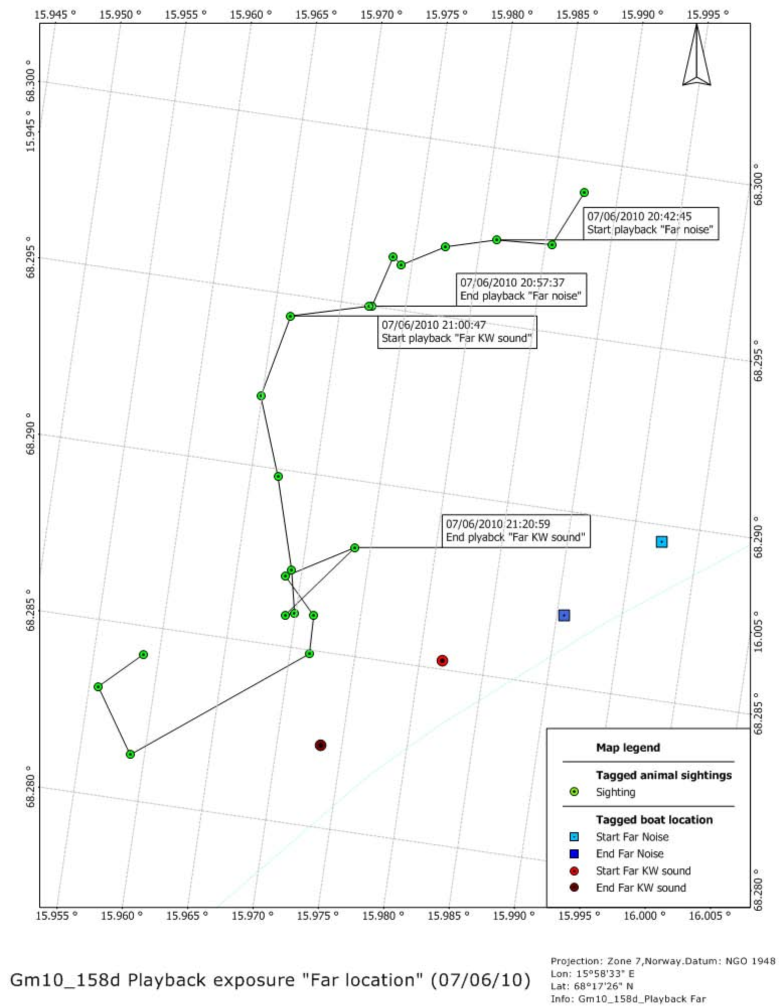

Figure 3. Track of a longfinned pilot whale before, during, and after playback of herring-feeding killer whale sounds. Note the lack of response to the control sound, but strong approach by the pilot whales after the start of playback of the killer whale sound.

RELATED PROJECTS

This study is an extension of the ongoing project "Cetaceans and naval sonar: behavioral response as a function of sonar frequency" Award Number: N00014-08-1-0984.

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